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THE DEVELOPMENT OF A LATERAL-CONTROL SYSTEM

FOR USE WITH LARGE-SPAN FLAPS

By I. L. Ashkenas
Northrop Aircraft, Inc.

FOR REFERENCE

NOT TO BE TAKEN FROM THIS ROOM

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THE DEVELOPMENT OF A LATERAL-CONTROL SYSTEM

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SUMMARY

A spoiler-type lateral-control system has been developed for use on the Northrop P-61 airplane. The lateral-control system is to be used with large-span flaps and consists of a thin circular arc spoiler, linked with a short-span plain aileron located just outboard of the spoiler. This unconventional lateral-control system has been accepted with enthusiasm by the pilots who have flown the airplane. They particularly appreciate its characteristics at high speed. The combination of light forces, favorable yawing moment, and low wing torsional moments, make it a very effective, easily applied control. The control available at and through the stall is also remarkably good, although this characteristic may be attributed, in part, to an exceptionally good wing stalling pattern rather than entirely to the use of the spoiler-type aileron. In the landing configuration, the lateral-control effectiveness increases automatically with the extension of wing flaps so that powerful control is available during the approach. There is, however, a decrease in effectiveness for the first 5 percent of the wheel travel with a resultant tendency for inexperienced pilots to overcontrol slightly at low speeds. The fact that the aileron can be fully used at the stall, however, more than compensates for this loss of effectiveness with flaps down and greatly enhances the airplane's landing performance.

INTRODUCTION

The trend toward the employment of ever-increasing wing loadings, desirable from the standpoint of high-speed performance, has necessarily worked against the maintenance of

low airplane landing speeds. In addition, increasing require-
ments for lateral control have limited the spanwise extent of
the wing flap (which is, in many cases, cut up by large, well-
faired engine nacelles) so that the attainment of a landing
speed, for a high-performance aircraft, of, say, 80 miles per
hour is no small accomplishment. In most cases the problem
is "solved" by filling the available wing span with a flap of
convenient chord and suffering the consequences as regards
landing speed. This quasi solution will not do in designs
where landing performance is deemed of great importance, and
it then becomes necessary for the designer to employ partial-
span flaps of improved quality: namely, multiple-slotted flap,
slotted plus split flap, Fowler flap, and so forth (see ref-
erence 1); or in extreme cases to devise ways and means of
utilizing the wing span normally devoted to ailerons. Both
the above-mentioned possibilities have been the subject of
considerable wind-tunnel and flight testing, the results of
which have indicated that the latter treatment, while obvious-
ly giving better results from the standpoint of maximum lift,
is fraught with many and varied difficulties as regards lat-
eral control — a drawback obviously not applying to the first
solution.

     In the case of a recent Northrop design (figs. 1 and 2),
landing and approach performance were deemed of sufficient
importance to warrant an attempted solution of the full-span-
flap problem. The choice of the lateral control arrangement
to be used was largely a matter of picking the lesser of a
number of evils, in view of the limited success of installa-
tions and schemes tested up to that time. A review of the
possibilities, however, showed that, as regards adequacy of
control, and mechanical simplicity, the spoiler-type lateral
control device had the advantage over slot-lip ailerons,
drooped ailerons, plain ailerons in combination with retract-
able flaps, or any of the other devices enjoying current fa-
vor. As a matter of fact, the only question mark concerning
its successful application to an airplane was its very erratic
hinge moments — a fault also appearing in some of the other
possible systems. Accordingly, the retractable aileron was
chosen as the most likely to succeed. The ways and means used
in obtaining satisfactory hinge moments and effectiveness are
given herein.

SYMBOLS

$C_h{}'$ scoop hinge-moment coefficient, $H/qb'tr$

b' scoop span

t width of scoop edge

r scoop radius

C_l rolling-moment coefficient

C_h balance aileron hinge-moment coefficient, $H/qS\overline{c}$

H hinge moment of control surface

S area aft of hinge line

$\overline{c}$ average chord aft of hinge

δ_a balance aileron deflection, positive downward

δ_s scoop deflection, positive downward

w wheel angle

b wing span

c local wing chord

P total tangential wheel force

l wheel radius

$pb/2V$ steady state wing tip helix angle

p rate of roll

V airplane forward velocity

k control-surface effectiveness, $\left(\dfrac{\partial \alpha}{\partial \delta}\right)$ for constant section lift coefficient

q dynamic pressure, $\dfrac{1}{2}\rho V^2$

ρ mass density of air

$$c_{h_\delta} = \frac{\partial c_h}{\partial \delta_a}$$

$$c_{l_p} = \frac{\partial c_l}{\partial (pb/2V)}$$

Subscripts

u   upgoing surface

l   downgoing surface

DESIGN CALCULATIONS

General.- It soon became apparent that the solution of
the hinge-moment problem would be perhaps the most difficult.
Researches conducted by the National Advisory Committee for
Aeronautics (reference 2) finally had produced a stable
hinge-moment variation for a modified circular-arc spoiler,
but only through the use of various vanes, vents, and pas-
sages, some of them apparently quite critical. Even then,
the resultant pilot forces were inacceptably high, and no
satisfactory method of trim control was available. Prelimi-
nary tests in the Northrop wind tunnel, directed toward the
possibility of obtaining stable hinge moments with a system
in which the center of rotation and the center of the arc
were not coincident, showed no promise; pressure measurements
corroborated the speculation that the extending hinge moments,
existing near the flush neutral position were due to the neg-
ative pressures acting on the exposed edge of the scoop.[1]
(These extending moments, when combined in an unsymmetrical
mechanical system, produce unstable pilot forces.) While
these extending moments were not directly proportional to the
upper-surface of the scoop, nevertheless their magnitude could
apparently be greatly decreased by a reduction of this area,
as shown in the tests of reference 2. It was decided, accord-
ingly, to minimize the inherent instability of the scoop by
the simple expedient of reducing its thickness as much as pos-
sible. Calculations, assuming the scoop hinge moments to be

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[1]The term "scoop" will hereafter be used to denote a
circular-arc retractable aileron in preference to the word
"spoiler," which connotes a device capable only of one-way
action and thus relatively ineffective on a wing already at
negative lift.

proportional to the product of scoop radius and upper-surface
area, showed that the contribution of a 1/4-inch-thick scoop
would be quite negligible compared to the allowable hinge
moment.

It was thus possible to provide lateral control with
very little attendant pilot effort, and there remained only
to build into the system a positive-centering tendency, some
means of trim control, and some degree of pilot "feel."
Since these properties are all, of course, available in the
conventional lateral control, one solution of the difficul-
ties enumerated was to link to the scoop system a complete
conventional aileron of small span. This compromise system,
moreover, consisted of components the characteristics of
which were sufficiently explored to allow of routine aero-
dynamic calculations. Its advantages more than outweighed
the loss of wing flap attending the use of a small conven-
tional aileron. There now existed a reasonable certainty
that a 90-percent full-span flap, say, could be made to work
with a relatively small amount of development time.

In the interests of a continuous wing flap and also as
a concession to conservatism, it was decided to locate the
conventional "balance" aileron at the wing tip. A prelimi-
nary wheel-force analysis, neglecting the scoop contribu-
tion, indicated that a plain-flap aileron occupying the outer
wing bay,[1] having a chord of approximately 15 percent of the
wing chord and a maximum throw of ±25°, would supply forces
in the neighborhood of 80 pounds wheel force at 80 percent of
maximum indicated level flight speed. (See reference 3.)
The scoop located adjacent to the balance aileron and at ap-
proximately 70 percent wing chord, to insure acceptable time-
lag characteristics, was laid out, in accordance with the
data of references 2, 4, and 5 and the method of reference 6,
to give a pb/2V = 0.07 in combination with the balance ai-
leron. Detailed calculations for the final configuration are
presented below to illustrate the methods employed.

Rolling moment.- The effective section twist (kδ) due to
the scoop projection above the wing surface was obtained by
comparing the rolling moments due to scoops (reference 2) with
those due to a conventional aileron (reference 7) occupying
the same span on a geometrically similar wing. The experi-
mentally determined effectiveness of the conventional aileron

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[1]Layout of the component parts of the lateral control
system was already limited by detailed structural design,
which it was not expedient to change.

was made the basis of the calculation; thus using the equation

$$C_l = 1/k \quad \partial C_l/\partial \delta_a \ (k\delta_a)$$

and substituting the value of the effectiveness $\partial C_l/\partial \delta_a$ obtained for the plain aileron and the known value of k for a 15-percent chord plain flap (reference 4) $C_l = -0.0016/0.38 \ (k\delta^\circ) = -0.0042 \ (k\delta^\circ)$, whereby the rolling moment is related to the section twist for the given plan form. The scoop rolling moments are transformed, with this equation, to values of effective twist $(k\delta)$. The results thus obtained are plotted as the dashed and broken lines in figure 3; they compare favorably with unpublished Northrop section data (full-line) if correction for chordwise location is made using the results of reference 8. While the proposed installation was to incorporate a slot behind the scoop for the purpose of improving the lateral control, it was apparent that at low values of the wing lift coefficient, the net effect of the slot was quite small (see fig. 3); and it would be conservative to use the section data at zero lift for design calculations made in accordance with the methods of reference 6. The balance-aileron rolling moments, computed in the same way, with no regard for possible interference effects were added directly to the scoop contribution to give the total rolling moment.

The geometry and rolling-moment calculations for the P-61 are presented below:

Scoop

Chordwise location............... 0.72c

Location of inboard end .... 0.49 $\frac{b}{2}$ ⎫

Location of outboard end .... 0.83 $\frac{b}{2}$ ⎬ $C_{l\delta}/k = 0.360$

Max. scoop extension (inboard)... 0.075c ⎭

Max. scoop extension (outboard) 0.080c

Aileron

   Type: plain flap, sealed gap

   Location of inboard end $0.83 \dfrac{b}{2}$
                                                              $\left. \vphantom{\begin{array}{c}1\\1\\1\end{array}} \right\}$ $C_{l_\delta}/k = 0.105$
   Location of outboard end $0.94 \dfrac{b}{2}$

   Chord aft of hinge line $0.17c$

   Max. deflection $\pm 22^\circ$

   $\left(C_{l_\delta}/k \right.$ are from reference 6 for A.R. 6.0 and $\lambda = 0.50$
       and antisymmetrical aileron deflection, C_{l_δ} denotes
       $\left. \partial C_l / \partial \delta_a . \right)$

For the average maximum scoop extension of $0.077c$, the corresponding effectiveness is $k\delta = 7.6^\circ$ (fig. 3). For the aileron, the data of reference 5 gives $k\delta = 22 \times 0.27 = 6^\circ$, which corresponds to 15° of fully effective travel at the wind tunnel value of k shown in reference 4. The maximum rolling moment coefficient at low lift coefficients is thus:

$$C_l = 0.360 \times 7.6/2 \times 57.3 + 0.105 \times 6/57.3 = 0.0348$$

This value was never checked on a complete wind-tunnel model, but similar calculations made for the wing-scoop geometry of the tests of reference 9 which became available at a later date, agree, within 5 percent, with the experimental results.

Hinge moments.- Hinge-moment measurements available for a plate-type scoop have been reduced to coefficient form in figure 4. The data, reduced on the basis of the spoiler radius and edge area, show little consistency in either test conditions or resulting hinge-moment coefficients. A consistent variation of spoiler opening hinge moment with lift coefficient, as found in reference 2, is not sufficient to bring the curves into agreement, nor are the theoretical upper-surface pressures, scoop retracted, any indication of the measured opening hinge moments. For the P-61 design the data most directly applicable (unpublished Northrop data) were used. Balance-aileron hinge moments were assumed linear and estimated, from the available data, to correspond to $C_{h_\delta} = -0.009$, including the reduction due to the response effect.[1]

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[1] The effect of angle of attack change due to rolling velocity.

With these data, the geometric relationships of figure 5, and the dimensions of the controls ($S\overline{c}$ = 5.88, $tb'r$ = 0.19 ft^3), the total wheel force was calculated for an indicated speed of 258 miles per hour, using the equation:

$$P\mathcal{l} = qtb'r \left[C_{h'_u} (d\delta_s/dw)_u + C_{h'_\mathcal{l}} (d\delta_s/dw)_\mathcal{l} \right] + 2qS\overline{c}\; C_{h_\delta}\; \delta_a\; d\delta_a/dw$$

The last term corresponds to the balance aileron contribution and is doubled because of the symmetry of the control system.

The results of this calculation are plotted in figure 6, where the spoiler contribution is seen to be quite negligible, provided a minimum gap is maintained. The possibility of overbalance near the neutral wheel position is illustrated by the case of the 0.004c gap. It was clear that small changes in the geometry, especially if they included an increase in spoiler thickness, could easily result in an unstable region near neutral. Since the magnitude of the unstable scoop contribution appeared largely unpredictable because of possible structural deflections, scale effect, or aerodynamic interference, a large balance tab (also used for trim) with adjustments for positive or negative boost was incorporated in the balance-aileron design. In this way, the balance-aileron contribution could be adjusted by flight test to be just sufficient to overcome the unstable scoop, a condition obviously giving the lowest acceptable pilot forces. Further, it was decided to resist strenuously any compromise with structural weight requirements which might increase the effective thickness of the scoop, since the success of the combined system might depend on this point.

Air loads.- In order to obtain the minimum allowable scoop thickness, accurate air load information was required. The data plotted in figure 7, show that the relative load distribution is independent of scoop deflection and the magnitude of the load is approximately proportional to this deflection. Since desirable wheel forces do not exceed 80 pounds at 80 percent of maximum indicated speed in level flight, it is physically possible for the pilot to obtain full wheel throw at very high speeds. In the present application, the scoop design condition was taken to correspond to full extension in a dive. Deflection of the control system, which would tend to reduce the available scoop extension, was neglected. Static structural tests showed that a 1/4-inch magnesium plate, formed to the proper contour and incorporating heliarc-welded hinge brackets, would take the design load thus determined. So far, the basic

requirements for a successful lateral control of the type
under discussion offered little difficulty. Some further de-
tails and conjectures that went into the complete design are
discussed below.

Scoop geometry.- The scoop-flap section geometry was
patterned rather closely after the configurations investigated
by the NACA in their spoiler-slot plus slotted-flap investiga-
tion. (See reference 2.) A rather blunt slotted-flap of ap-
proximately 25-percent chord was supported at three points in
the outer wing and actuated through a four-bar linkage which
gave approximately the optimum flap-slot configuration for the
important flap positions, (See reference 1.) The scoop was
placed just forward of the flap and hinged as near the inter-
section of the rear spar and wing mold lines as structure and
torque-tube size would allow. The scoop radius was determined
by the requirement that the down-travel of the scoop be at
least 40 percent of the up-travel, but that its maximum verti-
cal projection below the wing be limited as much as possible.
The latter requirement, it was thought, would minimize any ad-
verse effects due to down deflection; the first requirement
would permit approximately linear scoop extension with wheel
angle - a requisite of effective control near neutral - with-
out the high acceleration (and the accompanying "hard-spot")
that would result from a large differential motion. The slot
behind the scoop was made a constant width of approximately
1/2 inch, except for the lip which was brought as close to the
scoop as possible, and left uncovered at all times. The drag
penalty thus incurred, it was thought, would be little larger
than that associated with an unsealed trailing-edge flap, and
the alternative - to incorporate a plate along the upper edge
of the scoop, which would seal the slot for neutral and down-
ward scoop deflections - would drastically change the nature
and magnitude of the scoop hinge moments.

The final section geometry is shown in figure 8. It
should be mentioned that for the maximum extension of 65° the
lower edge of the scoop is above the upper wing surface by
approximately 1 inch. As indicated in reference 2, there is
no change in effectiveness with such an emergence of the scoop.

Flutter considerations.- The scoop was dynamically bal-
anced about its hinge line and the nacelle center line by a
linked counterweight; the balance aileron was statically bal-
anced about its hinge line by two attached weights. The pur-
pose of these precautions, of course, was to prevent the oc-
currence of wing-aileron flutter within the flying range of
the airplane. Later flutter calculations, using data available

from ground vibration tests, indicated that the fairly com-
plicated scoop counterweight could be eliminated by overbal-
ancing the balance aileron, provided the linkage between it
and the scoop were very rigid. In making such calculations
and also in estimating aileron reversal speed, it was neces-
sary to know the section pitching moments due to a scoop.
These were deduced from the data of reference 8 and are shown
plotted in figure 9 in the form of center-of-pressure loca-
tion. Assuming the elastic axis to coincide with the wing
quarter-chord point, these data indicate that, for a scoop
located at 72-percent chord, the wing torsional moments due
to the scoop extension are approximately two-fifths of the
moments due to the deflection of an equally effective trail-
ing-edge flap. This means that for a given wing rigidity the
reversal speed of a scoop control is about 60 percent higher
than that of a conventional control. If the elastic axis is
farther aft, the degree of improvement is even greater.

    Preflight changes.- When the system was completely in-
stalled in the airplane, it was noted that rapid manipulation
of the control wheel on the ground produced an appreciable
lag in the scoop motion because of the combined inertia and
flexibility of the system. To remedy this, the scoop torque
tube, which had been designed to strength requirements only,
was greatly stiffened, and, in addition, the inertia of the
scoop was lowered by drilling out enough 3/4-inch holes to
reduce its weight approximately 20 percent. (See fig. 8.)
A rough check in the Northrop wind tunnel indicated that the
loss in effectiveness due to a 30-percent area reduction, by
means of uniformly spaced holes, would be approximately 15
percent. (This result is in good agreement with measurements
of the effect of perforations on split flaps. (See reference
10.) To prevent the 10-percent loss corresponding to the
actual perforations (20-percent area reduction), the scoop
was fabric covered.

    Flight tests.- Preliminary flight tests of the new lat-
eral-control arrangement showed it to be generally satisfac-
tory from the standpoint of lateral-control forces and re-
sponse. Unfortunately, however, inspection of the scoop and
slot structure after each landing indicated that serious me-
chanical interference was occurring during flight. This in-
terference manifested itself primarily in repeated failure of
the lower slot lip which was progressively strengthened, and
in abrasion of the fabric scoop covering. It was deduced
from this evidence that, under the influence of air flow through
the slot, the scoop was vibrating quite violently, and, accord-
ingly, steps were taken to determine the conditions and modes

of vibration. Electrical strain-gage pickups were cemented
to the lip, the hinge brackets, and the scoop, which was left
uncovered for ease of inspection, and their responses were
observed in flight through use of an oscilloscope. These ob-
servations showed that above a relatively low airspeed the
scoop vibrated quite violently in a chordwise direction with
nodes at each of the hinge brackets, the amplitude of vibra-
tion being apparently limited by contact with the slot walls.
These vibrations were not felt by the pilot at any time, pre-
sumably because they included no vertical or rotational com-
ponents. It was believed that these vibrations were the re-
sult of air flow through the slot, a fact later substantiated
and reported in appendix I. In order to eliminate all flow
through the slot, a fairing strip covering the lower opening
was attached to the bottom of the wing. (See figs. 10a and
10b.) This expedient was immediately successful in eliminat-
ing all signs of vibration, and contrary to expectations was,
in the pilot's opinion, not appreciably detrimental to the
effectiveness with flaps up, even for small displacements of
the perforated scoop. (The fabric cover had by now been dis-
carded to facilitate production and maintenance.) The effect
of the slot cover on airplane performance was expected, if
anything, to be slightly beneficial, since the fairing was
located in a rather noncritical spot on the wing, and it
eliminated air flow losses through the slot. It remained now
to determine, quantitatively, the characteristics of the re-
vised arrangement prior to final acceptance.

Before this could be done, however, another problem arose
in connection with the approach and landing configurations.
It was found, with the wing flaps full down and regardless of
the power setting, that the airplane's lateral behavior was
unsatisfactory; pilots who flew the craft complained of diffi-
culty in controlling the airplane in rough air. Wind-tunnel
tests had shown no change in effective dihedral with flap set-
ting for the power-off condition, and since further flight in-
vestigation revealed a "dead spot," or region of poor effec-
tiveness in the lateral control near neutral, it was concluded
that herein lay the difficulty. During the flight investiga-
tions leading to this conclusion, it was discovered that seal-
ing the outboard flap slot with a metal plate improved the lat-
eral control and had a minor effect on maximum lift. This re-
sult was verified by further tests made with a more practical
cloth seal (figs. 10a and 10b), wherein the stalling character-
istics were fully investigated and found to be essentially un-
changed. (See fig. 11.) The large effect of the flap-slot
seal on the lateral control and its negligible effect on lift
characteristics are not yet fully understood; further research

on the problem, which has thus been solved practically but
remains unexplained theoretically, has been temporarily post-
poned. It is believed, however, that the effect of the flap
slot on lateral control is due to the fact that a small scoop
extension augments the flow through the flap slot, thereby
increasing the lift and counteracting the intended effect of
the original control deflection.

Examples of the rolling-velocity data obtained in flight
are shown in figures 12 to 18 wherein the wing-tip helix
angle, $pb/2V$, corresponding to equilibrium rate of roll is
plotted against scoop extension in percent of wing chord.
The data show that, with the flap retracted, the scoop slot
is not required to produce an essentially linear variation of
rolling velocity with scoop extension. Also, the control ef-
fectiveness remains practically constant for all the angles
of attack tested. It must be remembered, however, that these
curves of $pb/2V$ versus scoop deflection include the compo-
nent contributed by the "balance" aileron. There is thus no
necessary disagreement between these data and those of refer-
ences 2 and 11 which indicate respectively that, for a pure
scoop system, the slot is required for linear control and
that the effectiveness decreases with increasing lift coeffi-
cient. At any rate, the rolling-moment characteristics ex-
hibited here are practically ideal, $pb/2V$ being directly
proportional to the scoop extension, only, and having a max-
imum value slightly greater than that calculated.[1] The ef-
fectiveness in inverted flight has been found to be very good -
a result that surprises those who erroneously consider the
control a "spoiler" in the true sense of the word.

The original "dead spot" in the control effectiveness
with flaps down and scoop closed, is shown in figures 15 and
16, the extent of the ineffective region covering approximately
30 percent of full travel. Reference to the same figures will
show that the effect of sealing the flap slot is to eliminate
this region of poor control almost entirely. A further in-
crease in effectiveness is obtained by opening the scoop slot,
as indicated in figures 17 and 18. These results are all in
good agreement with the original speculations as to the cause
of the "dead spot" and indicate that a completely effective
roll control could be obtained with both flap slot and scoop
slot open. This possibility, however, was discarded from a

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[1]Taking C_{l_p}, the damping in roll, equal to 0.45 from
reference 6 and reducing the calculated scoop effectiveness
by 10 percent for perforations $pb/2V = 0.0324/0.45 = 0.072$.

practical standpoint, since a method to prevent vibration
with the open slot was not immediately evident; whereas the
scoop-slot cover and flap-slot seal could be readily applied
to the airplane with apparently no deleterious effects on
the stall, and without seriously limiting the available lat-
eral control.

The final configuration, embodying a perforated scoop,
scoop-slot cover, flap-slot seal, and zero aileron-boost tab
was flight checked to determine the magnitude of the control
forces. The results of these flights are shown in figure 19,
where, neglecting an appreciable scatter, it may be noted
that the pilot force varies approximately linearly with scoop
extension and dynamic pressure. Interpolating for a speed of
258 miles per hour indicated, the force corresponding to a
maximum scoop deflection of 7.7 percent is read at 82 pounds,
a value in close agreement with that calculated for this
speed. The forces required for lateral control may here be
seen to be relatively small for an airplane in this class.
As a matter of fact, the forces required for lateral trim,
even under single engine operation, are so light, that it has
been found feasible to eliminate, entirely, the aileron tab.

CONCLUDING REMARKS

1. The results of this development program indicate, to
some degree, the success obtained with this new lateral-con-
trol arrangement. Another indication is the universal enthu-
siasm with which pilots have accepted this unconventional
control. They particularly appreciate its characteristics at
high speed. The combination of light forces, favorable yawing
moment, and low wing torsional moments, make it a very effec-
tive, easily applied control. The control available at and
through the stall is also remarkably good, although this char-
acteristic may be attributed, in part, to an exceptionally
good wing stalling pattern rather than entirely to the use of
the spoiler-type aileron. In the landing configuration, the
lateral-control effectiveness increases automatically with the
extension of wing flaps so that powerful control is available
during the approach. There is, however, a decrease in effec-
tiveness for the first 5 percent of the wheel travel with a
resultant tendency for inexperienced pilots to overcontrol
slightly at low speeds. The fact that the aileron can be
fully used at the stall, however, more than compensates for
this loss of effectiveness with flaps down and greatly en-
hances the airplane's landing performance.

2. The scoop vibration that occurred inside the slot during the preliminary flight tests can be eliminated by closing the lower-surface slot. Closing the slot had little effect on the control flaps-up, but with flaps down, the effect was detrimental unless the flap slot was sealed.

3. The important aerodynamic characteristics of the system – control effectiveness and pilot forces – have been calculated with sufficient accuracy to make the application one of routine aerodynamic computation. It is believed that the use of methods presented will give satisfactory results for the aerodynamic design of spoiler-type lateral-control systems.

Northrop Aircraft Corporation
    Hawthorne, Calif., October 31, 1945.

APPENDIX I

SCOOP VIBRATION TESTS

In order to determine the cause of and to eliminate the severe chordwise scoop vibration encountered in flight tests of the P-61 airplane at all speeds in excess of 140 miles per hour, a full-size wooden mock-up of the airplane outer wing panel, equipped with a production scoop, was tested in the Northrop wind-tunnel building. The maximum velocity through the slot was equivalent to a dynamic pressure of about 11 inches of water, and was obtained by the use of a Rees blower which was connected to the under surface of the wing by a series of canvas ducts. The static pressure in the bag below the scoop was equivalent to a height of 17.5 inches of water. These pressures remained fairly constant throughout the tests. Scoop vibration frequencies were measured with a strobotac, while vibration amplitude was measured with a marker plate in contact with a marker attached to the upper edge of the spoiler. During the first few tests, it became apparent that the scoop vibrations were very sensitive to duct characteristics. At first, the main duct from the blower was attached to the scoop duct by means of a square wooden frame but it was thought that this entrance to the scoop duct was causing some interference with the flow, so a cylindrical sheet metal section was substituted for the wooden frame. This new

arrangement made a marked difference in the vibration char-
acteristics.

With the scoop deflected up 30°, vibrations of 5000
cycles per minute and amplitudes of 1¼ inches were measured;
and it was impossible to stop these vibrations by any mechan-
ical means such as rollers, felt pads, or guides in contact
with the scoop either in the scoop slot or above the wing.
With the scoop fully deflected and completely out of the wing,
it was possible to stop the vibrations with a rubber-roller
damper mounted above the wing and in contact with the front
scoop face. Then various aerodynamic means were tried to
control the scoop vibrations; these means consisted of span-
wise strips of felt seal in the scoop slot, metal vanes to
deflect the air flow off the rear face of the spoiler, spring
loaded doors to seal off the flow through the scoop slot when
the scoop was completely out of the wing, small spoilers at-
tached to the leading and trailing edges of the scoop aileron,
an auxiliary slot in the wing mock-up behind the scoop aileron,
variation of the scoop slot gap at the lower surface of the
wing mock-up, various degrees of roughness applied to the
rear scoop face, and spanwise grooves machined in the rear
scoop face. The auxiliary slot eliminated scoop vibrations
at all deflections; spanwise roughness strips of thin string
or tubing applied to the rear scoop face almost entirely pre-
vented vibrations; and coarse sand or cork roughness sprinkled
on lacquer over the lower 40 percent of the scoop rear face
entirely eliminated vibrations except with the scoop com-
pletely out of the wing mock-up, where a rubber roller contact-
ing the scoop easily damped the vibrations. All other means
tested proved to be partially or entirely unsuccessful in elim-
inating the vibration.

Subsequent tests on the same setup, with a strain gage
installed on the front and rear faces of the scoop near its
top edge at the center of the unsupported span between the
outboard supports indicated violent vibrations of the scoop
in its original condition and no vibrations when the rear
scoop face was roughened.

Three flight tests were then made with the P-61A airplane
which had the right-hand scoop slot open, right-hand scoop
roughened with cork in lacquer, and strain gages attached to
the inboard scoop halfway between supports at the top edge.
Strain-gage and oscillograph readings were calibrated approxi-
mately by means of ground vibration tests before flight. Re-
sults of these flight tests indicated no vibrations at speeds
below 275 miles per hour in the cruising configuration with

the scoop in neutral and deflected up and down. At speeds of
275, 300, 325, and 350 miles per hour, cruising configuration,
and at speeds of 140 and 160 miles per hour, flaps fully de-
pressed, low-frequency vibrations of about 1100 cycles per
minute were encountered, which were sometimes spasmodic. At
350 miles per hour, the amplitude of vibration with the scoop
neutral was about 3/16 inch. On one of the flights, vibra-
tions of the order of 400 cycles per minute with an amplitude
of less than 1/16 inch were encountered at a speed of 335
miles per hour.

   Comparison of these flight test results with the vibra-
tion test results obtained with the scoop in the original
condition shows that roughening the rear scoop face had a
very favorable effect in raising the speed at which vibration
was encountered.

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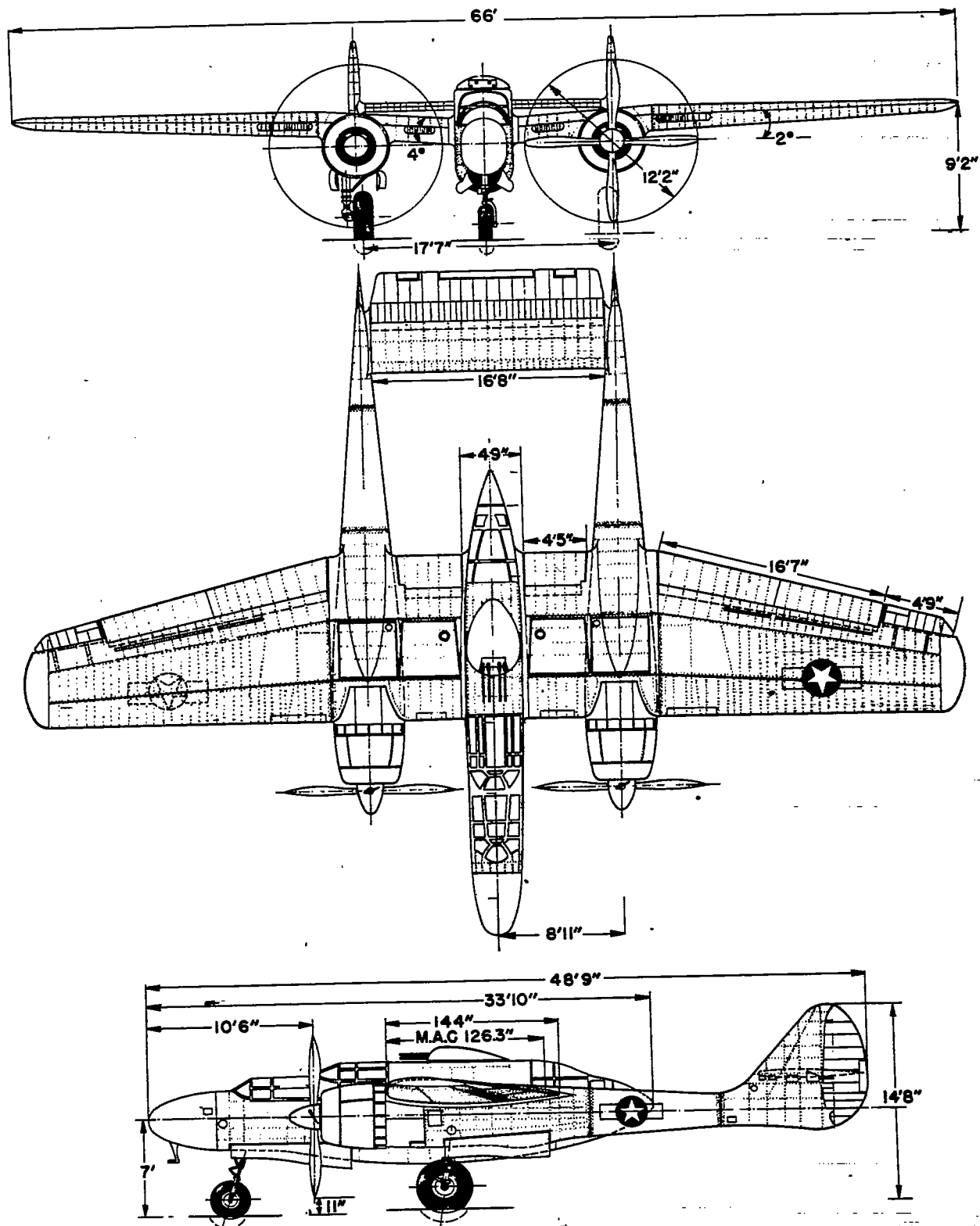
Figure 1.— Three view drawing of Northop P-61 airplane.
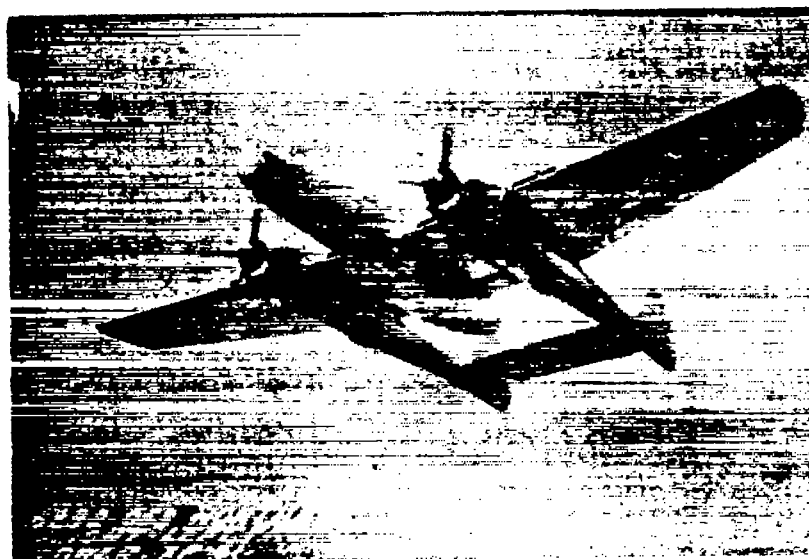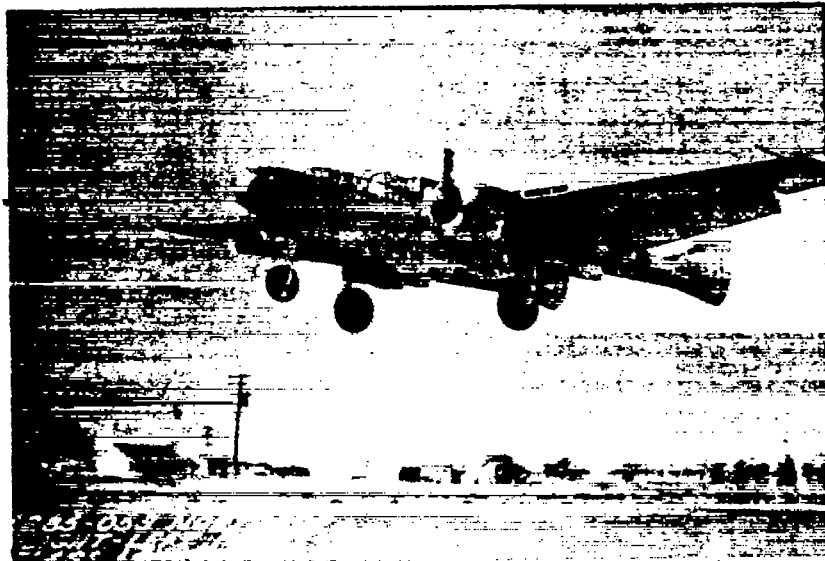
Figure 2.- Photographs of the Northrop XP-61 airplane
in flight.
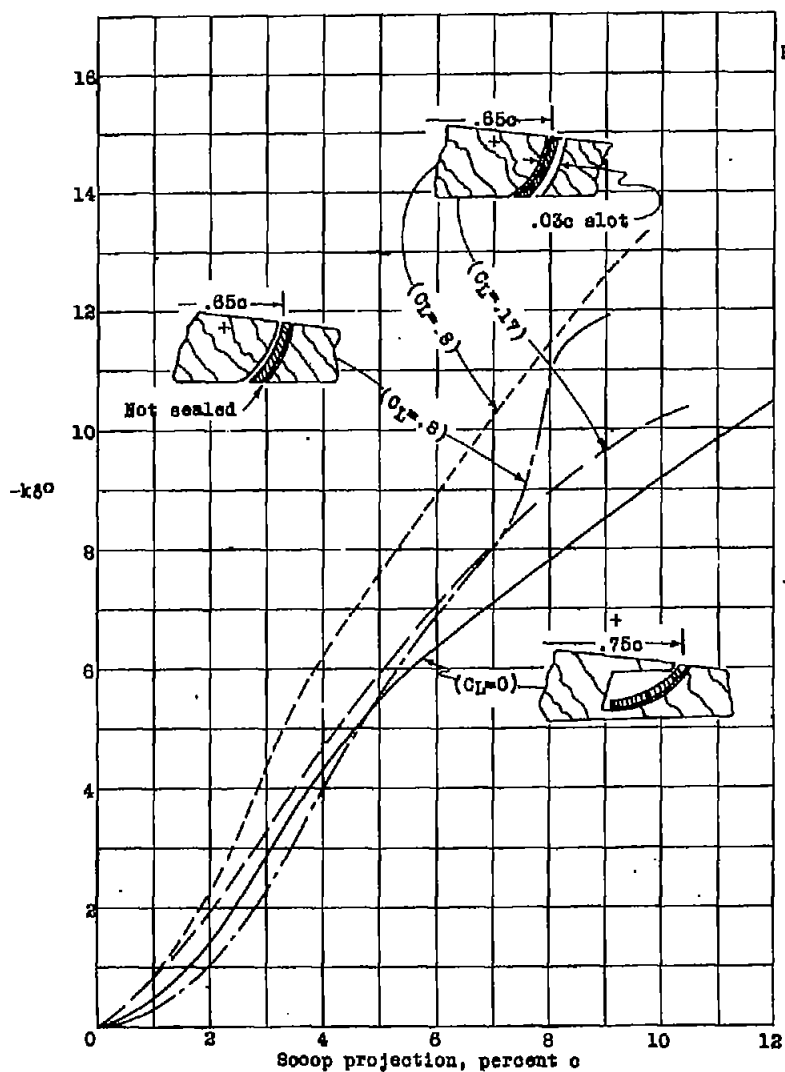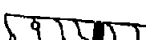
Figure 3.- Scoop effectiveness with flaps retracted.

Figure 4.- Scoop hinge-moments with flaps retracted.
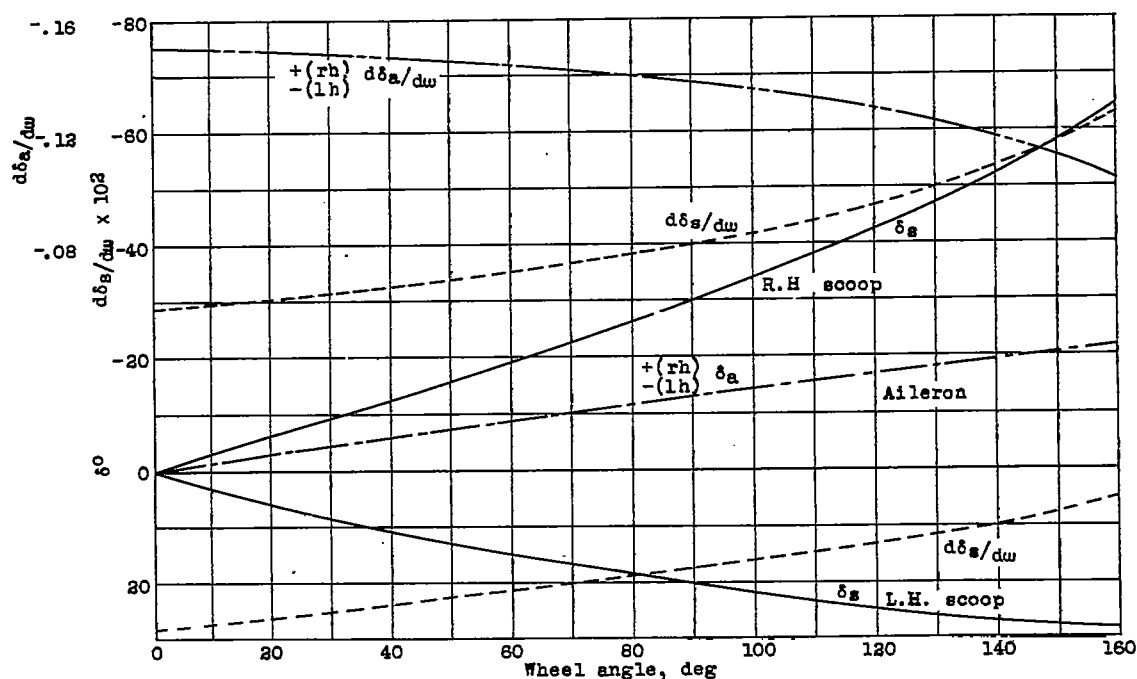
Figure 5.- Control system geometry.
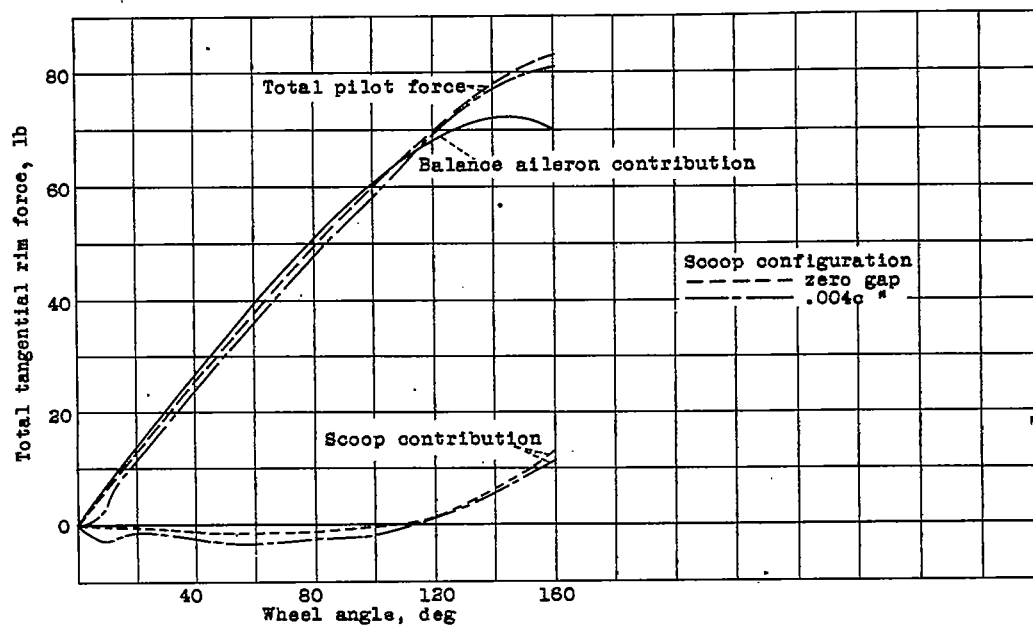
Figure 6.- Pilot-force curves.

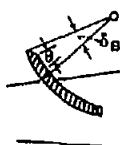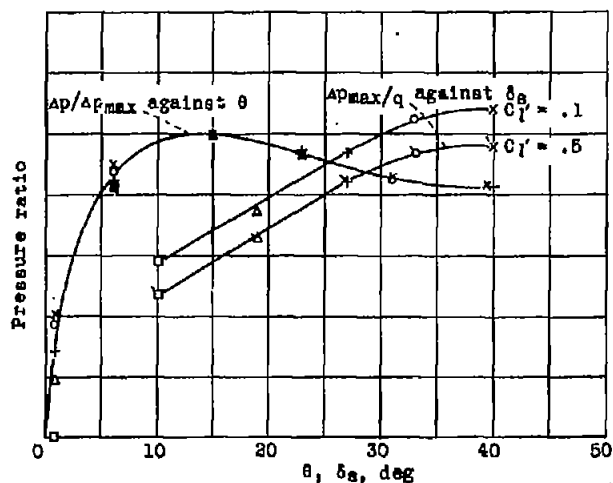Figure 7.- Pressure distribution over scoop.

Front face of scoop at 72 percent c

Outboard section 83 percent of semispan

Inboard section 49 percent of semispan
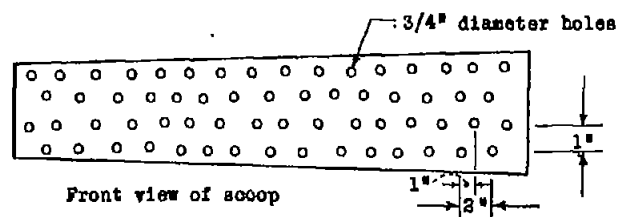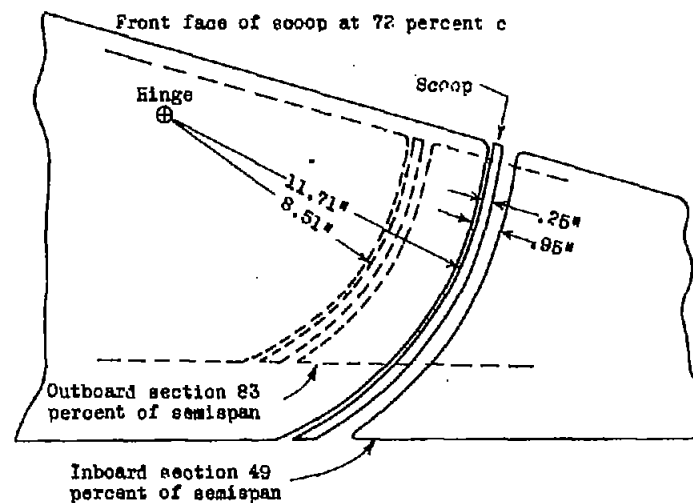
Figure 8.- Scoop geometry.

Front view of scoop

3/4" diameter holes

δ_B defines scoop deflection
θ " any point along scoop arc
Δp is pressure difference between front and rear scoop faces
C_l' is section lift coefficient, $\delta_B = 0^0$
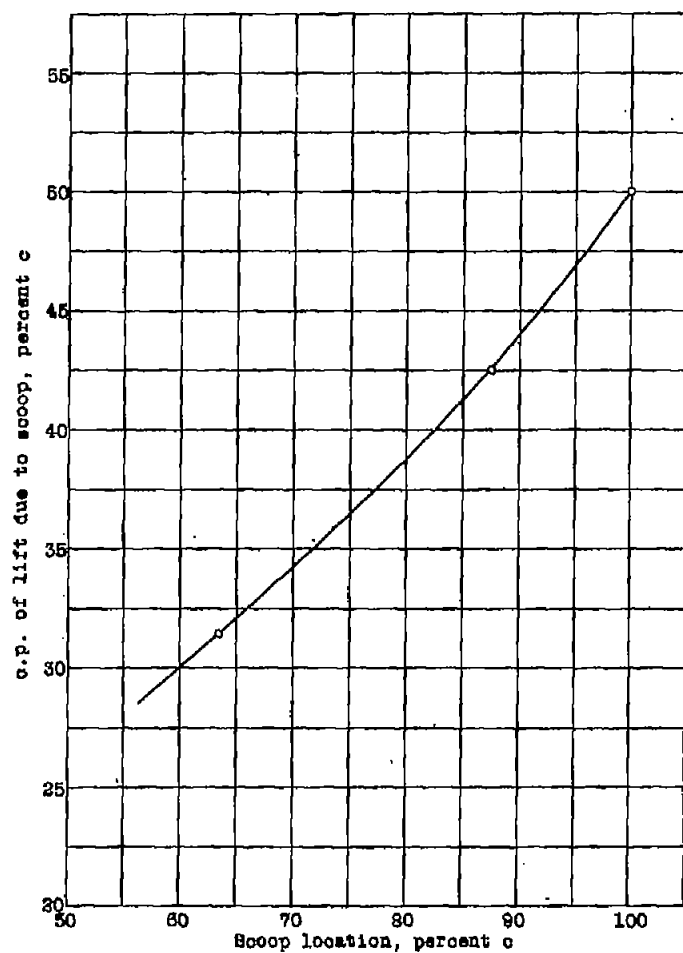
Figure 9.- Center of pressure of scoop lift at $\alpha = 0^\circ$.

Spoiler station 0, outboard
Spoiler station 133.57, inboard

Slot fairing

1.10
1.28

5.25
7.30

7.70
9.80
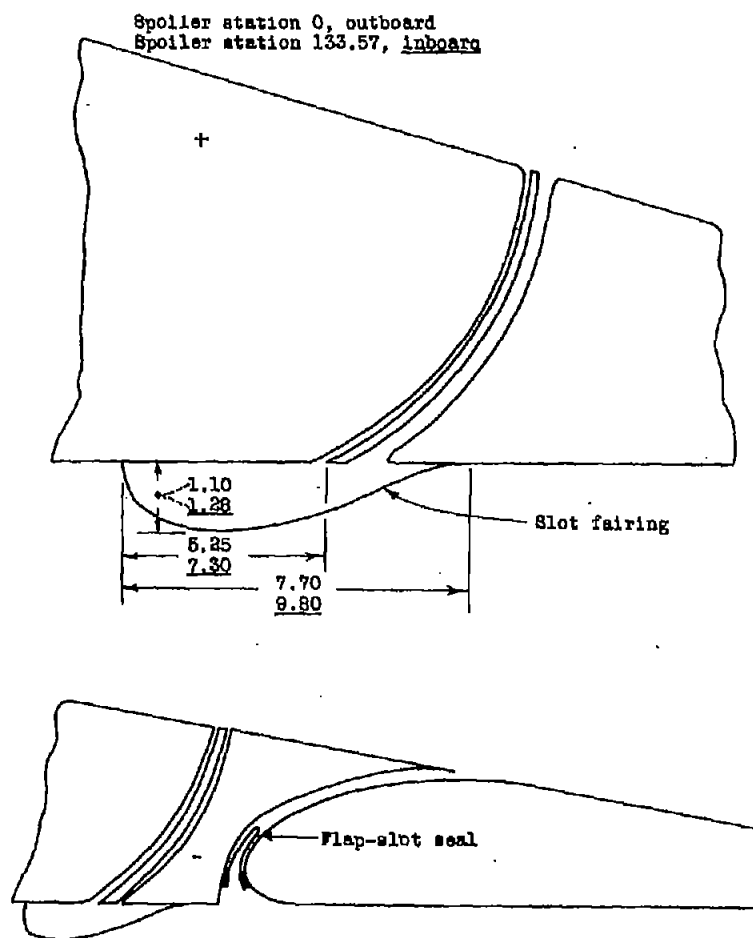
Flap-slot seal

Figure 10a.- Details of scoop slot fairing and the flap-slot seal.
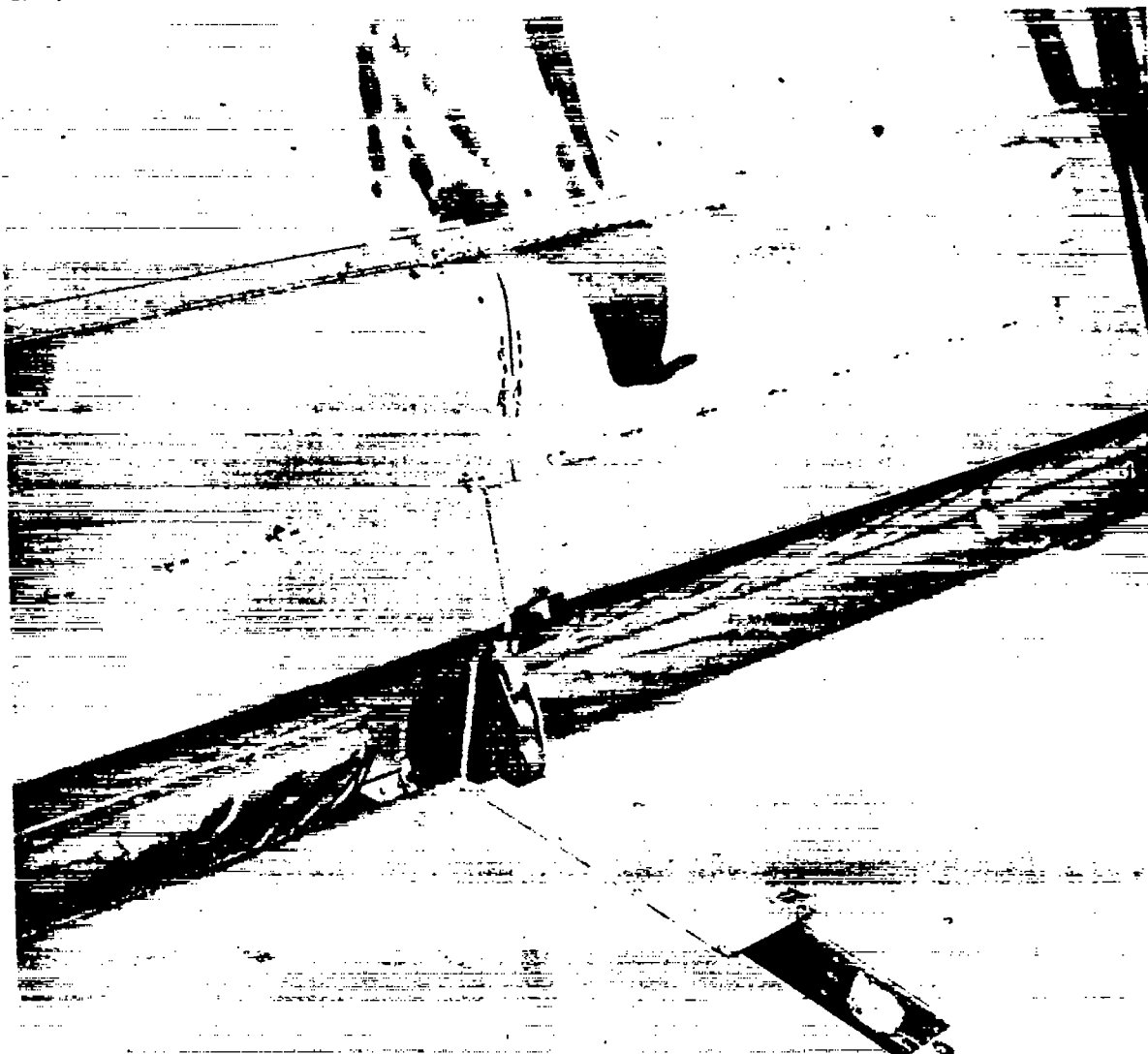
Figure 10b.- Photograph of fairing strip and flap seal on
P-61 airplane.

o Flap slot open
□ " " sealed
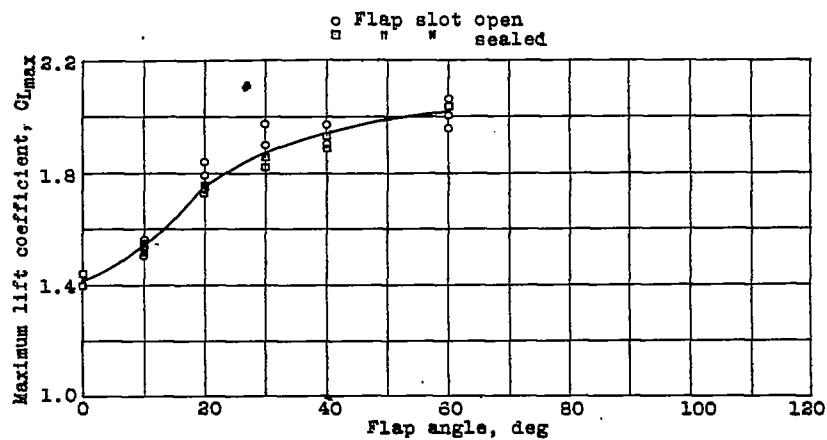
Figure 11.- Effect of flap seal on airplane maximum lift coef-
ficient. Propeller windmilling.
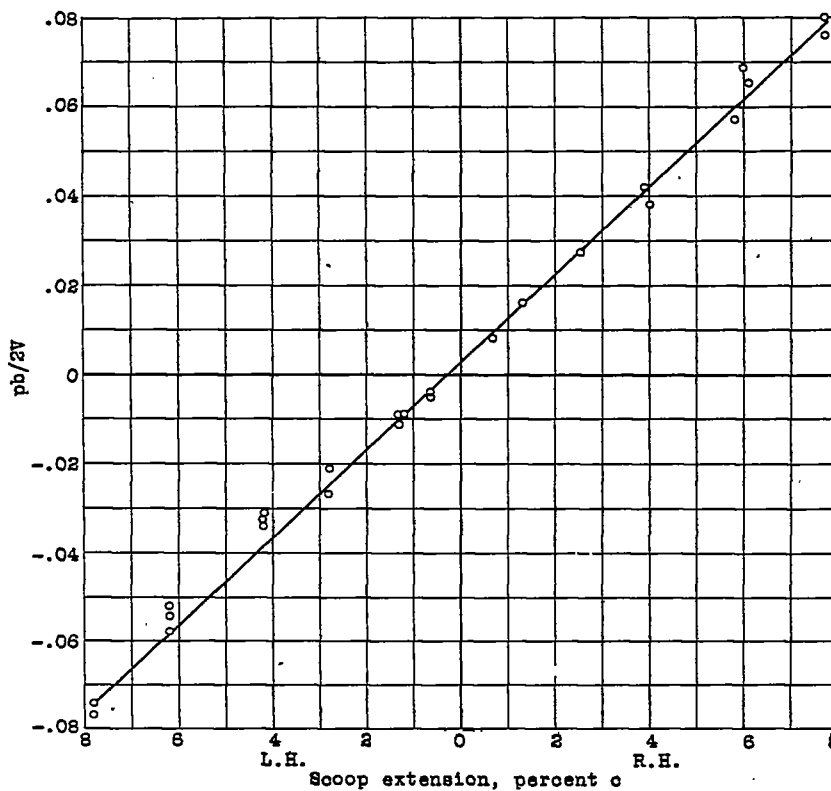
Figure 12.- Rate of roll at 135 mph, (C_L = .86) flaps and gear
up, scoop slot closed, flight No. 31.
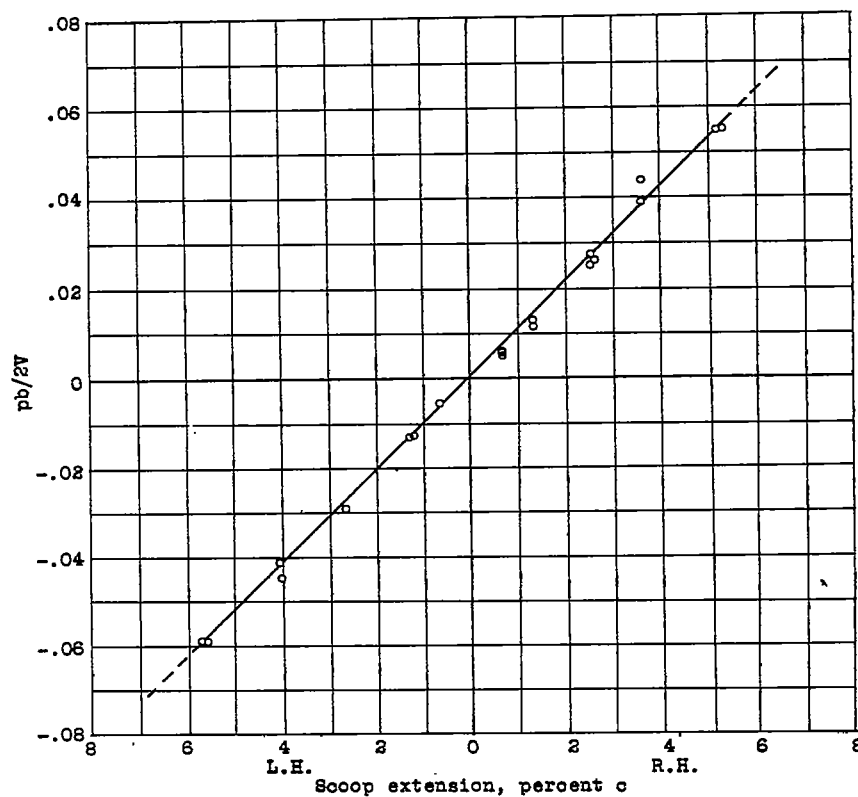
Figure 13.- Rate of roll at 285 mph, (C_L = .19) flaps and gear up, scoop slot closed, flight No. 31.
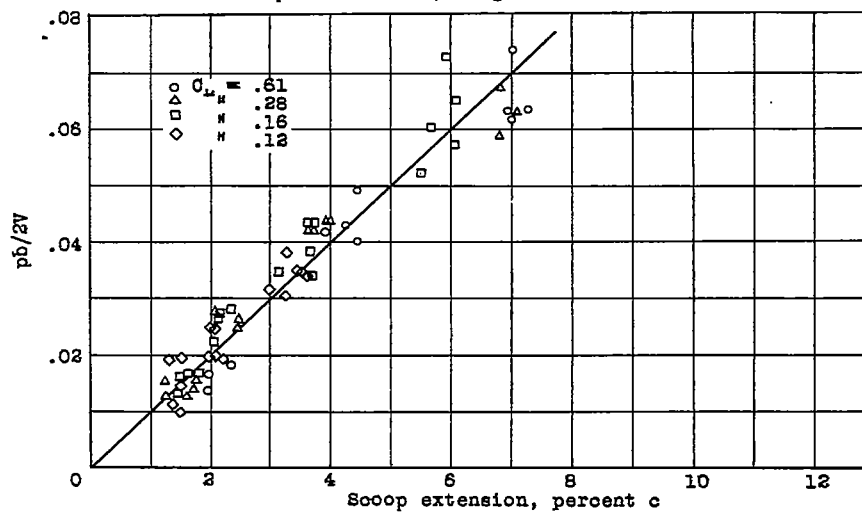

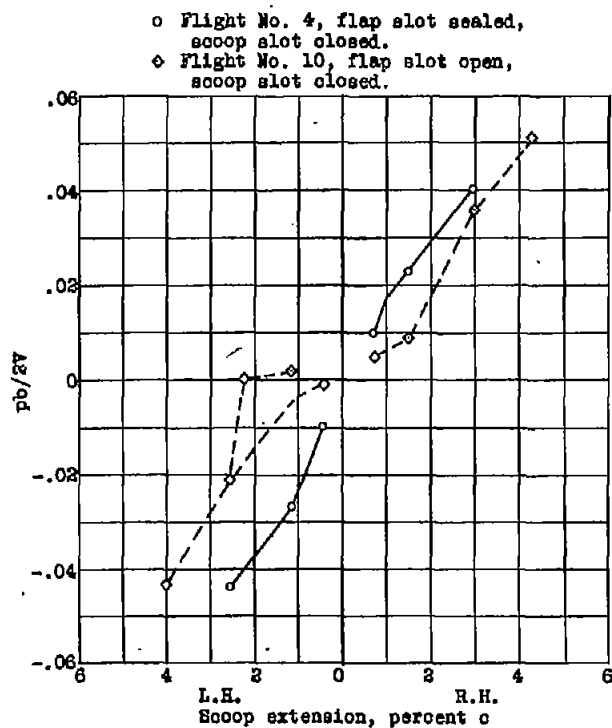Figure 14.- Rate of roll flaps up, scoop slot closed, flight No. 53.

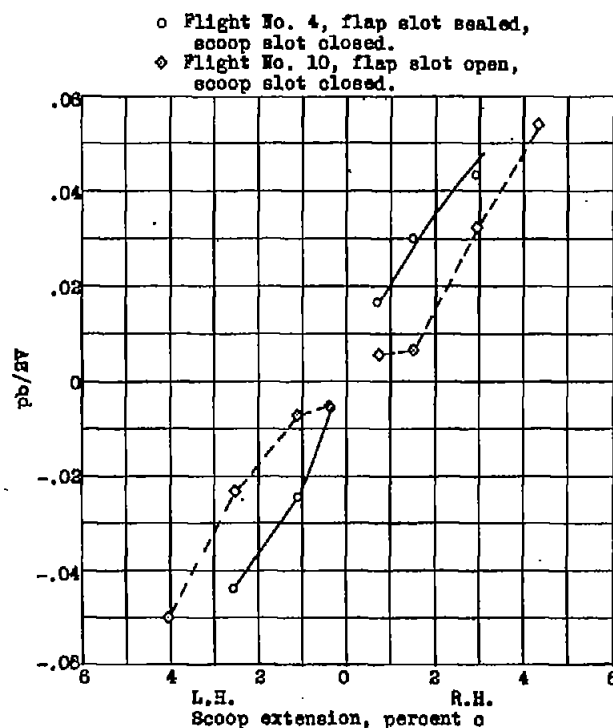Figure 15.- Rate of roll at 100 mph, (C_L = 1.57)
flaps and gear down.

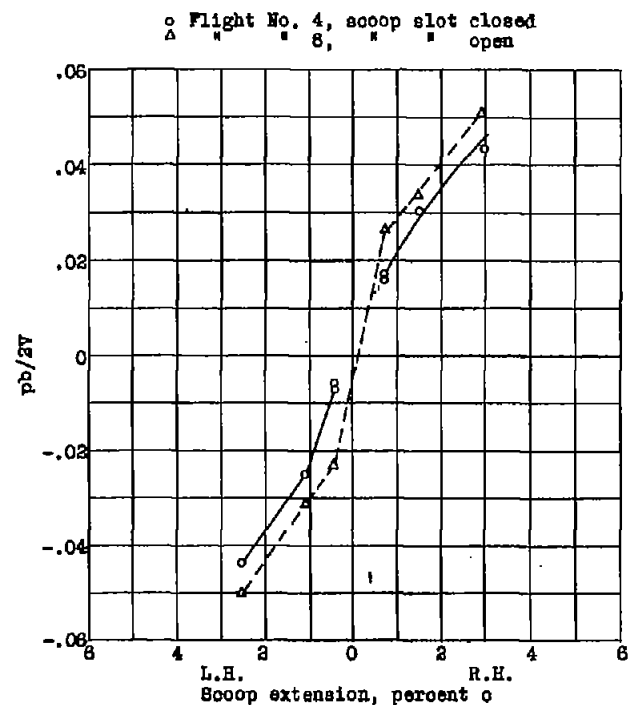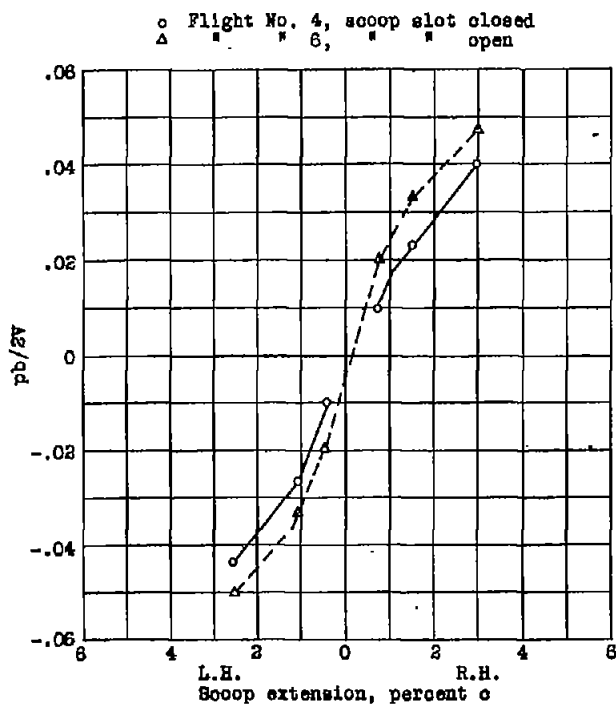Figure 16.- Rate of roll at 160 mph, (C_L = .61)
flaps and gear down.

o Flight No. 4, scoop slot closed
Δ "   "   " 6, "   "   open

o Flight No. 4, scoop slot closed
Δ "   "   " 8, "   "   open

pb/2V

pb/2V

L.H.   R.H.
Scoop extension, percent c

L.H.   R.H.
Scoop extension, percent c

Figure 17.- Rate of roll at 100 mph, ($O_L = 1.57$)
flaps and gear down, flap slot sealed.

Figure 18.- Rate of roll at 180 mph, ($O_L = .61$)
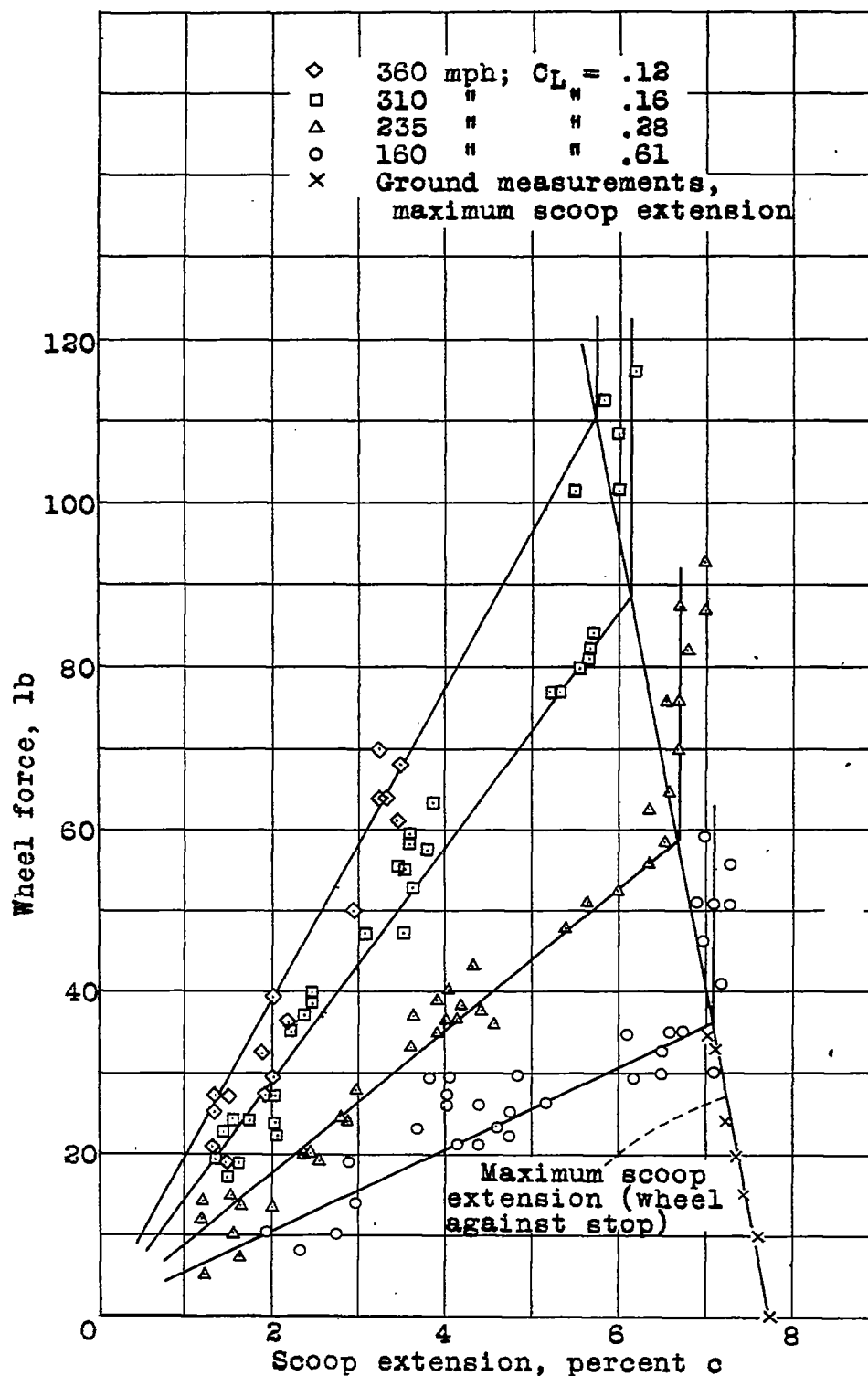flaps and gear down, flap slot sealed.

Figure 19.- Wheel force against scoop extension,
flights 52, 53 and 56.